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Ship's cargo handling system with the optical fiber sensor technology application

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ABSTRACT

It is now well recognized that the optical fiber technology, because of its advantages, may be applied in measuring different nonelectrical and electrical values in various ship's systems. One of the most important advantages of optic technology over conventional is the ability to use one single strand of optical fiber to replace sensors and their wires required for measuring some considerable electrical and non electrical values in ship's systems. Fiber optic sensors are immune to electrical interference and corrosion and do not require to create electrical pathway.

This paper outlines the application of fiber optic in some elements in cargo handling on board a ship. The application of optical fiber technology were proposed by authors based on elements of cargo handling system and associated equipment (longitudinal and transversal strength of ship's hull, temperature readings at cargo space and reef container, draft readings, liquid level in tanks sounding pipe). Real time monitoring cargo handling elements and cargo carried as well, together with optical fiber sensors, provide the knowledge of the seaworthiness and cargo worthiness of a considered ship.

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1. Introduction

In the past two decades, the optical fiber technology, because of its advantages in the data transmission and its simple installation, compared to the traditional information transmission technologies, has completely prevailed in telecommunications and computer networks. Optical fibers are also attractive for applications in sensing, control and instrumentation. In these areas, optical fibers have made a significant impact. [7]

Sea transport is consequently under significant pressure to reduce costs and improve their effectiveness. [5] Fiber optic technology may have an important role in the design of modern merchant ships. Shipboard requirements of the new generations of ships include a greater use of electrical machinery, automation and control for increased turnaround and reduced crew to manning. Fiber optic technology has the ability to use a single strand of the optical fiber as a sensor for measuring some considerable electrical and non electrical values in the ship systems. That is one of the most important advantages of the optic fiber technology over a similar conventional technology. Additional advantages of fiber optic sensors are immunity to electrical interference and corrosion. Furthermore, for that type of strands it is not necessary to create an electrical pathway. [3]

In its simplest form, a fiber optic sensor consists of a light source, an optical fiber as a sensing element, and a detector. The light source may be a broadband, a light-emitting diode, or a laser, depending on the nature of the sensor. When the sensing element is an essential part of the fiber, the sensor is called an intrinsic sensor. When the fiber is only used to guide light to and from the sensing element, the arrangement is known as an extrinsic sensor. Physical properties of light such as amplitude, frequency, phase, and polarization passing through the sensing element can be affected by the change in the environment surrounding of the sensing part of the sensor. These changes can easily be detected and recorded with the optical measurement instruments.

Optical fiber serves as both the sensor and the conduit for the optical sensing signals. The condition of the mayor ship's system (propulsion, steering system and cargo handling system) can be monitored by this fiber optic sensing technology from the central monitoring stations (positioned on the ship's bridge) by using optical cable, or in same cases, wireless. Significant data from the central station can be transmitted through the satellite link to the party involved in the seaborne process. It may also be possible that the responsible person at the owner's office can use the Internet to log on to the ship's monitoring stations and see in real time the necessary data of the specific ship's system and compare these by a computer model to resolve the problem.

A fast turnaround during maintenance and repair is important for the type of ships to keep the operating cost down. This necessitates a fast and through inspection, which would be greatly improved on board a ship with a built-in self diagnostic capability. [10] On liner ships, fast turnaround is even more important to ensure a high level ship's maintaining schedule. [1] The concept of self-monitoring elements of the ship's system is very appealing from both the economic and the safety points of view. Continuous monitoring of structural loads, vibrations, liquids level reading, and temperature could lead to ongoing improvements in the design. Fiber optic technology could substantially reduce of life-cycle costs as it would provide the means of checking structures, equipment, from the date when the ship has been built to the date she will be sent to the demolition yard.

This paper aims providing some primer measurement capability optic technology only on cargo handling system on board a ship. The paper illustrates some of the diverse area at the cargo handling system on board ships which can be benefited by applying optical technology in three ways: improved performance, reduced costs, and improved safety. The measurement by a fiber optic sensing system can be taken from the optical sensor built into the ship's structure, ship's equipment, or means of multimodal, intermodal or integral transportation which has to be monitored during the sea transport. In order to benefit the cargo handling system, optical sensors can be applied to determine strain, pressure, liquid level and temperature. A useful monitoring system should be able to discern critical events, change the scan frequency and perform a preliminary evaluation of which data should be stored and which can be discarded. The considered information, such as response intensities and deformations modes of scan strain should be converted into a graphic form, which can be quickly assessed by the officer on watch (OOW) on board the defined ship and by the responsible person at the owner's office.

The real time monitoring system on board a ship would permit more effective maintenance as the responsible officer would know from the monitoring system that the considered element of the cargo handling system has either sustained appreciable damage or been excessively loaded. The proposed system can also be used to perform structural fatigue analysis and to predict the remaining life of the structural components.

Realizing this opportunity, the authors have proposed the application of an appropriate optical fiber technology on the following elements of the cargo handling system and on the belonging equipments: monitoring longitudinal and transversal strength of the ship's hull, temperature/humidity readings in cargo spaces and refrigerated containers, forward-midship-aft draught readings, and liquid level readings on tank sounding pipes.

2. Longitudinal/transversal ship's hull strength monitoring

The strain is an element that refers to the internal tensile or compressive condition of the ship's structure resulting from the difference between local loading forces and buoyancy. The longitudinal strength is generally represented by the maximum bending moment that the hull cross-section can withstand [15]. The ship's hull, in the longitudinal direction, has been subdivided into compartments in order to protect the ship, the crew and the cargo she carries from possible serious damages incurred by accidents. Minimal requirements for the ship's strength have been specified by the national and international rules and regulations.

The ship's hull, when floating or moving through the waters, is exposed to various types of forces. The magnitudes and points of those forces depend on the shape of the ship's hull. Parameters which have an impact on the pattern of acting forces on a ship's hull are the following [9]:

– the weight of the empty ship (light ship weight),
– the weight and distribution of the cargo,
– distribution of fuel, ballast, provisions, fresh water etc,
– hydrostatic pressure on the hull determined by the surrounding water,
– hydrodynamic forces resulting from the movement of the ship on the waves, etc.

The total upward force (buoyancy forces) will equal to the total weight of the ship (displacement of the ship) when a ship is in ideal calm water. A ship is not a rectangular homogeneous object and, locally, this equilibrium will not be realized [14]. Shearing forces, which also lead to longitudinal tensions, and the bending moment are appearing as the differences between the local upward pressure of buoyancy and the ship's local weight. The mentioned facts are important to predict the quantification, both global and local, of loads acting on the ship's hull. Additional forces generate on the transverse section and the increased bending moment as well which will appear because of the facts that the total buoyancy distribution in the waves situation will change. As opposite to this, the weight distribution of the ship remains unchanged [16].

The development of various new methods in determining the hull girder strength is based on the continuous improvement of the knowledge regarding the behaviour of the ship's hull under various conditions.

The basic aim of this part of the paper is to obtain a possibility to determine the hull girder strength by the use of optical fiber sensors, which may be used as handy to verifi-

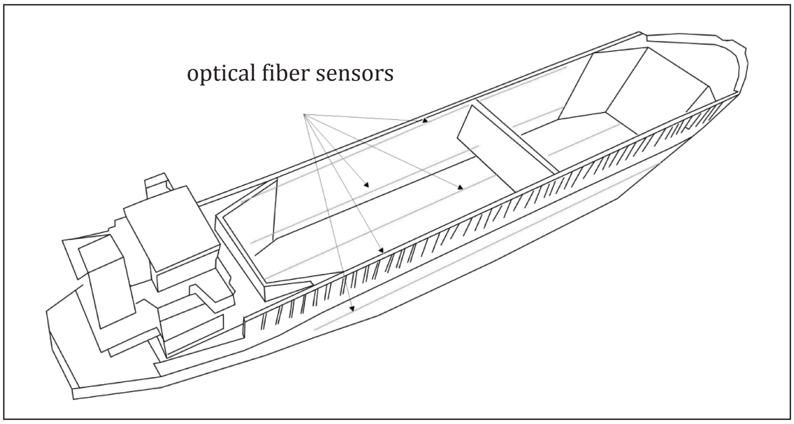

Figure 1 Position of optical fiber sensors in longitudinal direction

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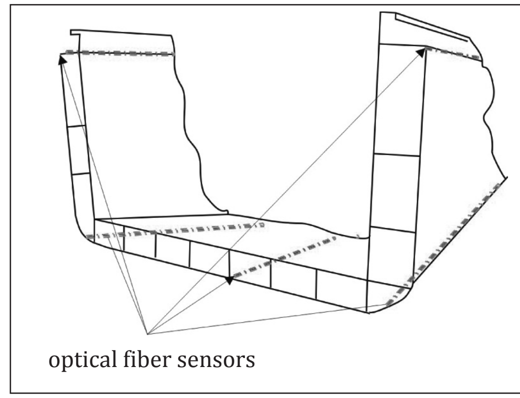

Figure 2 Position of optical fiber sensors in transversal section

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cation of transversal, longitudinal and local strengths for a momentary loading condition and to help make timely decisions in the event of an emergency which has been arising from an accident. Ships are subjected to the action of a corrosive environment. The external structures at the waterline and upper deck, as well as the internal tank structures, are the areas mostly exposed to corrosion. The magnitude of the growing corrosion may be controlled by several techniques, but despite this measure, reduction of thickness takes place [1]. The conditions of the ship's hull element are periodically surveyed by the classification society. Data of the ship's hull element condition obtained by the distributed optical fiber sensor can be useful for the classification society aimed at the verification of the longitudinal strength.

The most sensitive indicators of the longitudinal strength are elements of the ship's hull bottom and the deck and because of that the position of the optical fiber sensors will be as shows on Figure 1 and Figure 2.

Figure 2 is a sketch of a transversal ship's section, which characterizes the geometry of a defined ship and ignores many unessential details. This transversal section may be a double hull tanker, a bulk carrier, a container carrier, a single hull tanker or any other type of the vessel used in a commercial maritime transportation process.

The proposed system permits monitoring of not only the magnitude of strength, but also its variation along the length of a continuous uninterrupted optical fiber. The distributed sensors also permit an easy and reliable comparison of a parameter at different points (the same interrogator takes measurements at different points) and the sensor cable measures at every point along the length with no "dead spots" [9].

The ship's integrity may be monitored at real time by using optical fiber sensors. The collected data could be used to obtain a global condition of the ship's hull. The obtained data could especially be relevant in the case of [9]:

– prediction of the ship's structural damage,
– verification of the ship's longitudinal/transversal strength,
– verification of the ultimate longitudinal strength after an accident,
– prediction and verification of the longitudinal strength during the ship's ballast exchange.

Such system may be useful to predict the ship's structural damage especially at the time when the ship's hull is exposed to extreme loading forces (the ship fails to escape from stormy weather or when the cargo and/or ballast are improperly loaded). The ship's master can obtain the necessary information of the residual and ultimate longitudinal strength after an accident in real time buy using the optical fiber technology. The mentioned system can also collect data of the hull monitoring system which can be used in the optimization of the ship's design and the operational availability.

Continuous real-data collection under different sea conditions and commercial operations enables the ship's master/officers and other users interested in (ship's owner, classification societies, ship's insurance) to make correct conclusions about the actual ship's hull state and about the necessary actions that have to be taken. Data collected by the use of the proposed optical fiber sensors can be kept as history track on a VDR – Voyage Data Recorder, and can also be stored on a personal computer.

3. The application of the fiber optical technology in measuring the mass loaded or discharged cargo by using the draught survey method

Draught surveys have been accepted as an accurate and convenient method of establishing the weight of cargoes (especially bulk) on board ships. It is an international commercial custom that the weight of seaborne bulk cargoes is determined by draught survey [4]. The draught survey is a method by means of which the weight of mass loaded onto or discharged from a vessel are determined by draught readings measurements on the draft marks at the bow, midship and stern [14]. The basic principle upon which the draught survey methodology is based is the Archimedes' Law of Buoyancy.

Several key factors have to be taken into account and measured before the weight of the cargo loaded or discharged can be determined. This includes:

- the initial and final draught readings
- the density of the sea or river water,
- changes in the quantity of ballast between the initial and final draught readings,
- changes in the consumables on board the ship between the initial and final draught readings (fuel oil, water, etc.).

The accuracy of a measuring mass loaded or discharged cargo by the draught survey method could vary due to both the systematic and the accidental errors. The most important key factors in weight determination are the initial and final draught readings [11]. By analyzing errors of draft readings which have an influence on the calculated quarter mean draught, on the ship's displacement calculated on the quarter mean draught basis and on the final displacement, the authors have reached the conclusion that the influence of an error made in draught readings is the most important, especially for midship's draught readings.

Instead of classic visual draught readings, the authors have proposed draught readings by the use of optical fiber sensors. The inner draught reading system enables draught readings inside the ship's hull. Pipelines should have to be connected across the bottom valve on the seawater level. Sounding pipes connected on the main pipeline should have to be positioned at the inner side of ship's hull, opposite of the reading marks on the outside board of the ship. The liquid level optical sensor for measuring sea level measurements should have to be built in the sounding pipe of the inner draught reading system.

The proposed sensors should have to be composed of a POF (Plastic Optical Fibre) cable and a measurement device – the OTDR (Optical Time Domain Reflectometer), which consist of an optical probe light source, optical detector, processor and display. A coil of fibre is built on a cylindrical tube vertically positioned in a sounding pipe of the inner draft reading system (Figure 3). The measurement points are defined by small areas created by side-polishing on a curved fibre and the removal of a portion of the core. Those points are distributed on each full-turn of a coil of fibre. The changes between the refractive indices of air and liquid generate signal power proportional to the position and level of

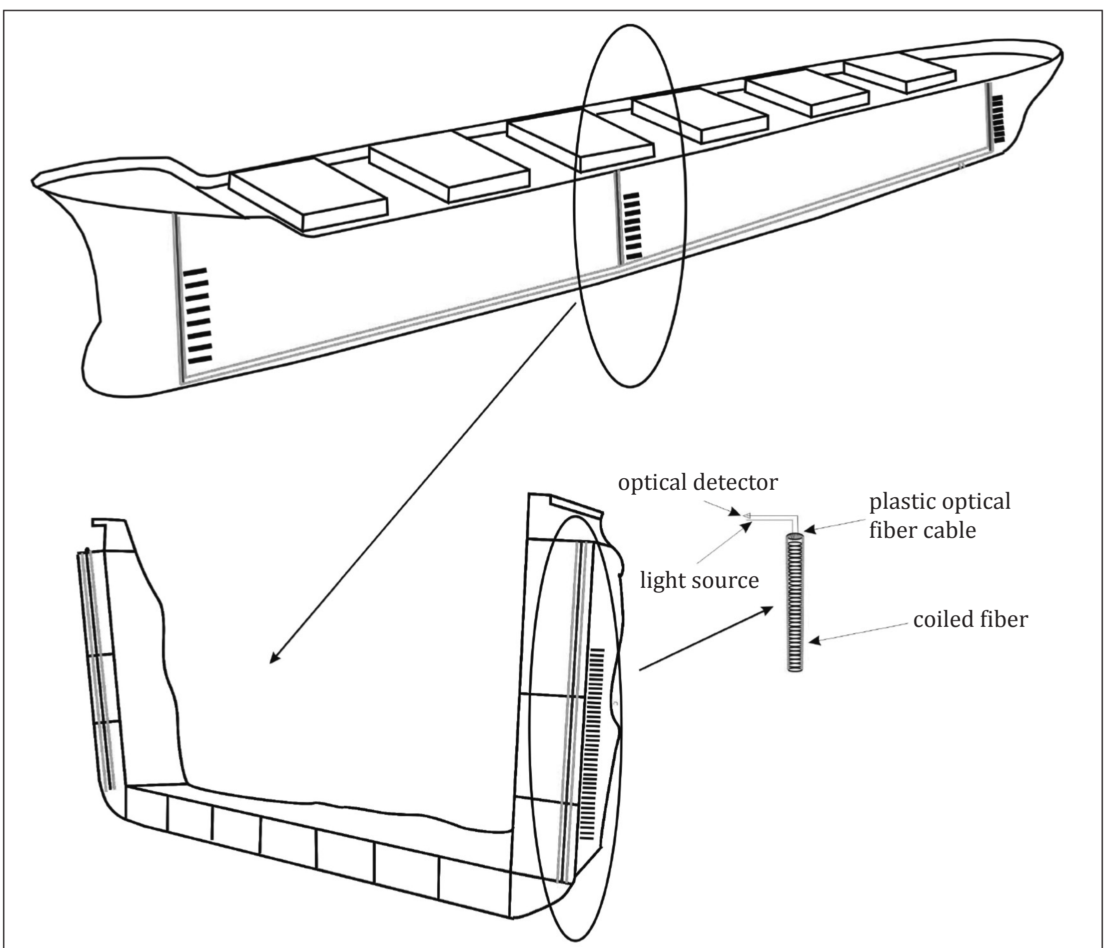

Figure 3 Proposed draught reading system with optical fiber sensors

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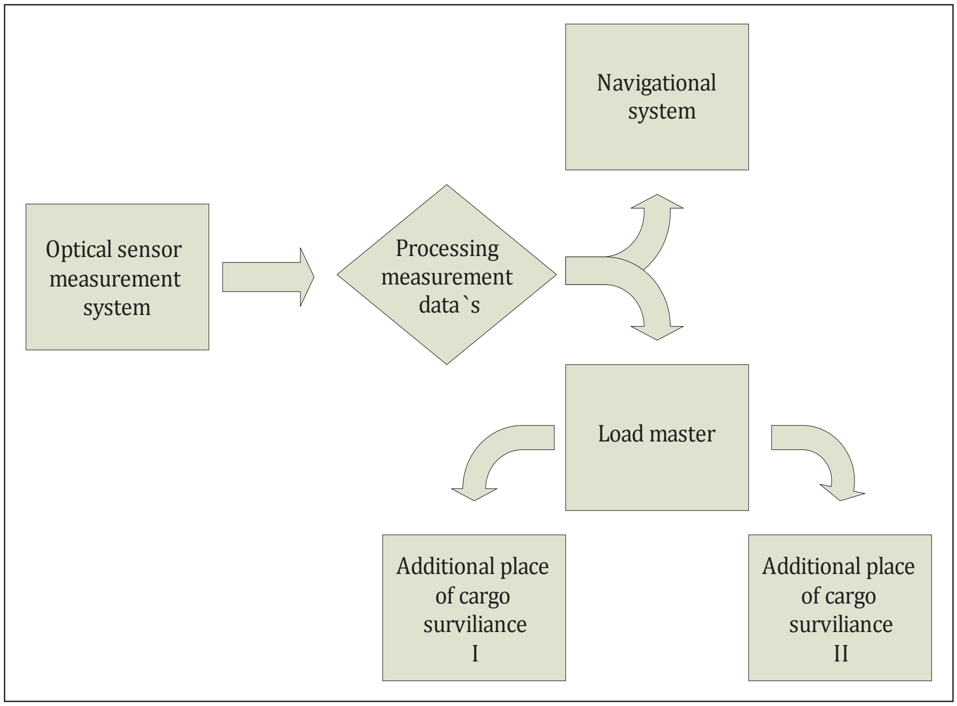

Figure 4 Distribution of draught reading data to different ship systems

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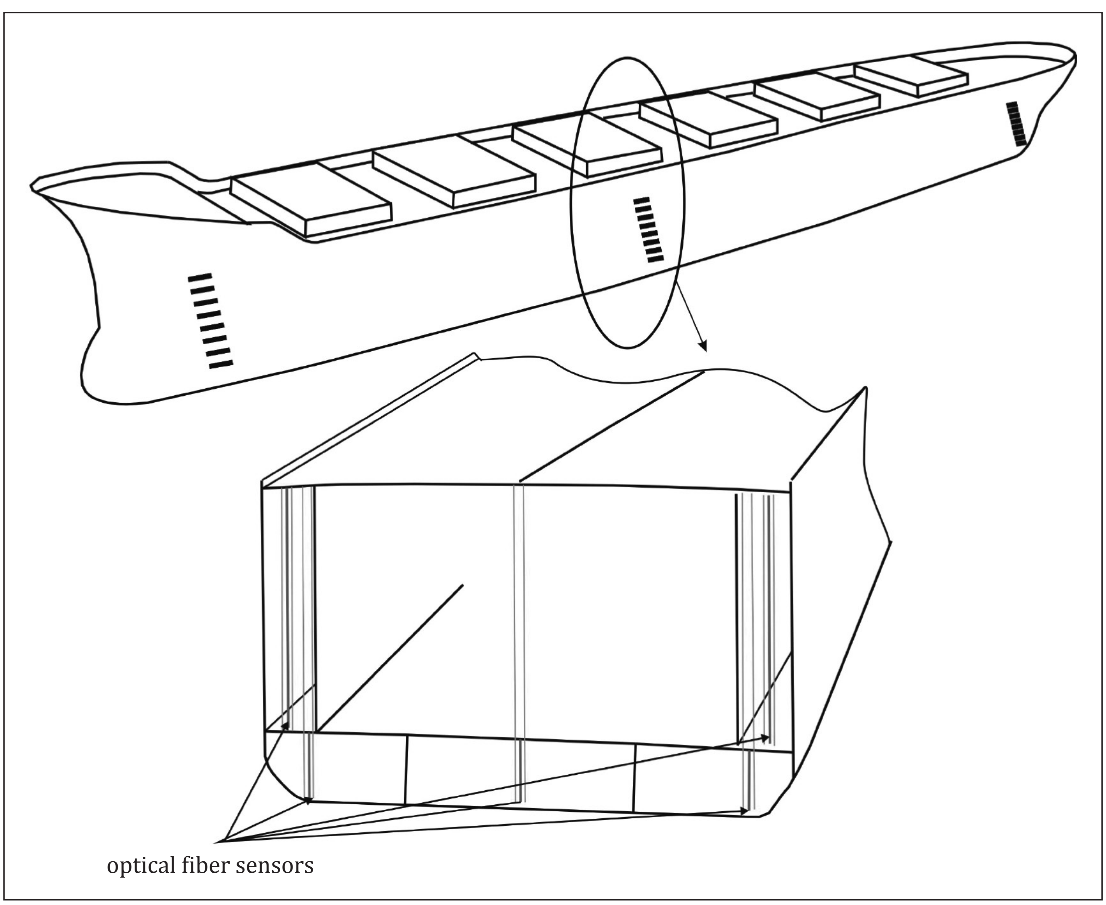

Figure 5 Measuring liquid level in the ship's tank by the proposed optical fiber sensors

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the liquid [7]. The described sensors require the use of the radar-type backscattering measurement method to make real-data continuous measurements on unbroken optical fibers. The basic method of the optical time-domain reflectometry concept uses OTDR instruments for the analysis of a fiber from one end only [13]. The OTDR provides a trace that plot signal level versus distance, displaying event information such as signal loss due to level of the liquid. In that case draught readings obtained by the optical fiber technology are without human error.

The ship's navigational system and the ship's Loadmaster should have to be feed with draught readings obtained by the installed optical sensors. In that way the officer on watch (OOW) at the navigational bridge, in order to improve the ship's safety manning, has real-data draught readings directly from the navigational system. Simultaneously, draught readings data obtained on Cargomaster provide relevant information relevant to the ship's momentary loading condition to the cargo officer on duty.

4. Liquid level readings in different tanks

The quantities of liquids in ballast and consumables tanks (fuel oil, fresh water, etc.) and cargo tanks are usually determined by the use of the classic sounding methods[1]. The quantity for each tank is shown in special tank tables which must be approved by an appropriate classification society. The sounding of tanks has to be done with a calibrated steel sounding tape covered with a liquid finding paste. The sounding liquid level must be corrected for trim and list. The liquid level reading is the main data to enter into the approved tank tables. The accuracy of a taking liquid level readings method could vary due to both the systematic and the random errors.

The liquid level reading can be performed by the use of optical fiber sensors. Liquid level optical fiber sensors, which consist of a coil of fiber built on cylindrical tube, should have to be vertically positioned in each sounding pipe of the tank. Sensors of the proposed optical liquid level reading system operate on the same principles as sensors explained on the inner draft reading system.

The proposed optical liquid level reading system on board a ship should enable more accuracy for the determination of the liquid quantity in ship's tanks (ballast, consumables, and cargo tanks). Furthermore, human error as one of the most significant error in the tanks sounding method should have to be eliminated by the use of the proposed optical fiber technology.

5. Monitoring temperature/humidity in a ship's cargo space and in refrigerated containers

Ship's holds are closed space in which the surrounding atmosphere or more precisely the temperature and humidity are liable to differ from those of the surrounding area. A cargo carried in ship's holds may adapt to conditions or it may create a completely different environment. Some kinds of cargoes may not be affected by even consider atmosphere changes and thus do not require atmosphere checks, but some kinds of cargoes are not so tolerant and could require constant monitoring of the atmosphere during the ship's voyage. On board multipurpose and bulk carriers the atmosphere data have mostly been collected visually by a responsible ship's officer.

Refrigerated ships are equipped with the atmosphere reading equipment in each cargo space and in refrigerated containers. Full container ships are equipped with their own temperature/humidity measurement and recording instruments.

Monitoring atmosphere in maritime transport technology enables the producers to deliver perishable goods to purchasers thousands of nautical miles away with no substantial loss in freshness and quality. By the use of efficient and accurate cooling systems, modern refrigerated carriers are able to maintain temperatures/humidity with

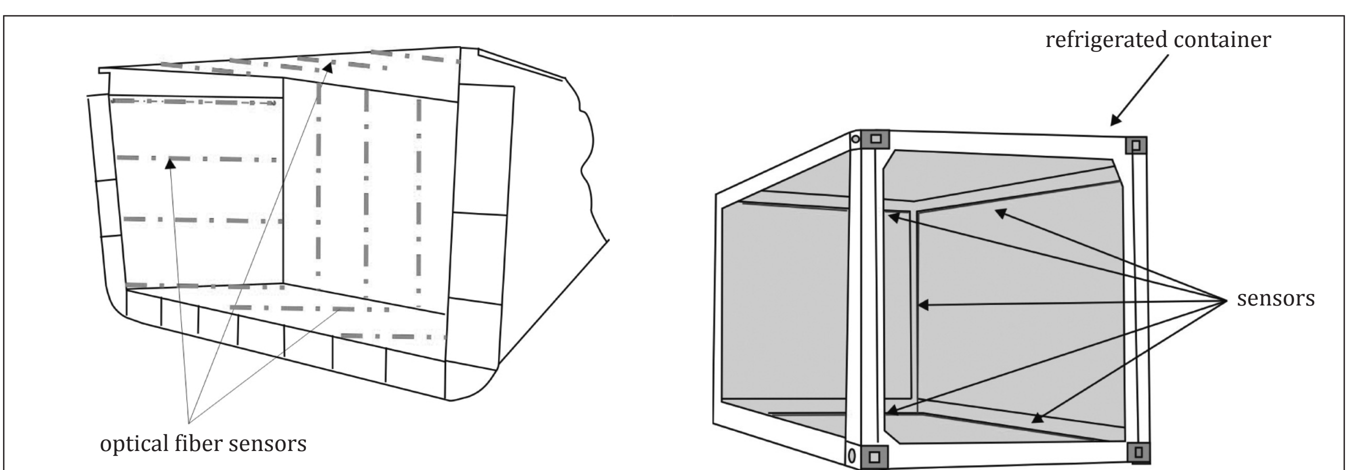

Figure 6 Monitoring temperature and humidity in a ship's cargo space and in refrigerated containers

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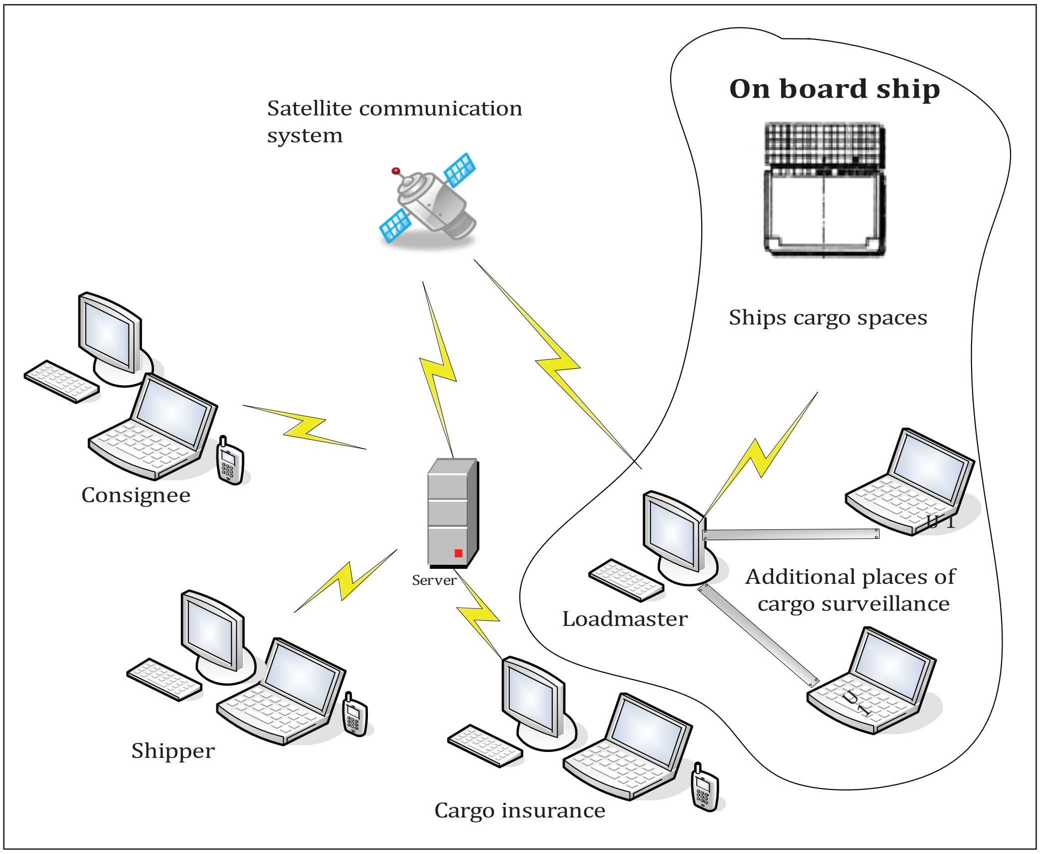

Figure 7 Controlling process and exchanging data from the ship's cargo space and refrigerated container

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great accuracy, with the possibility to extending the shelf life of perishable goods and thus expanding the types of perishables that can be shipped in refrigerated area without spoilage.

A remote monitoring system enables the collection and transmission of relevant data electronically, so that, in such cases, often physical checks are not required. The remote system activates an appropriate alarm and warning system thus minimizing losses should different kind of problems arise. All the installed measurement reading sensors continuously take readings of the atmosphere data in the surrounding area at the positions where they are installed.

A fiber optic sensor could be used to monitor permanently the temperature and humidity. It is important to point out that it is possible, in this way, to assess some significant parameters of the cargo condition in the cargo space or in a refrigerated container at each area covered by an appropriate fiber optical sensor. The proposed system permits a continuous monitoring of not only the temperature and humidity values, but also their variations along the length of a continuous optical fiber in use. Sensors distributed in holds or on container wall permit an easy and reliable comparison of relevant parameters at different check points and the sensor cable measures the parameters at every point along the length of the cable [8].

Data collected by the use of appropriate optical fiber sensors can be kept as a history track on different devices (as for example on the VDR – Voyage Data Recorder), but can also be stored on a personal computer.

The collected data can be sent to the internet network via satellite communications and they become available to all the interested users (shipper, consignee, cargo insurance). The kind of information obtained can be used to attend to good conditions for the goods as well as for further logistic planning.

6. Load forces and strain effects monitoring on board container ship stacking system

The length of a very large container carrier exceeds 300 m, and significant acting forces with high magnitude act on her hull in the longitudinal/transversal direction and on the container lashing system as well. The speed of large container ships has steadily increased, especially in the past few years to keep on scheduled ship's rotation. The rules and regulations (national and international – such as Load Line, MARPOL, SOLAS, Rules of Classification Societies, etc.) specify the minimal requirements and assume that the ship is operated according to the accepted standard for seaworthy and cargoworthy [12]. On the basis of some marine accidents, it could be concluded that

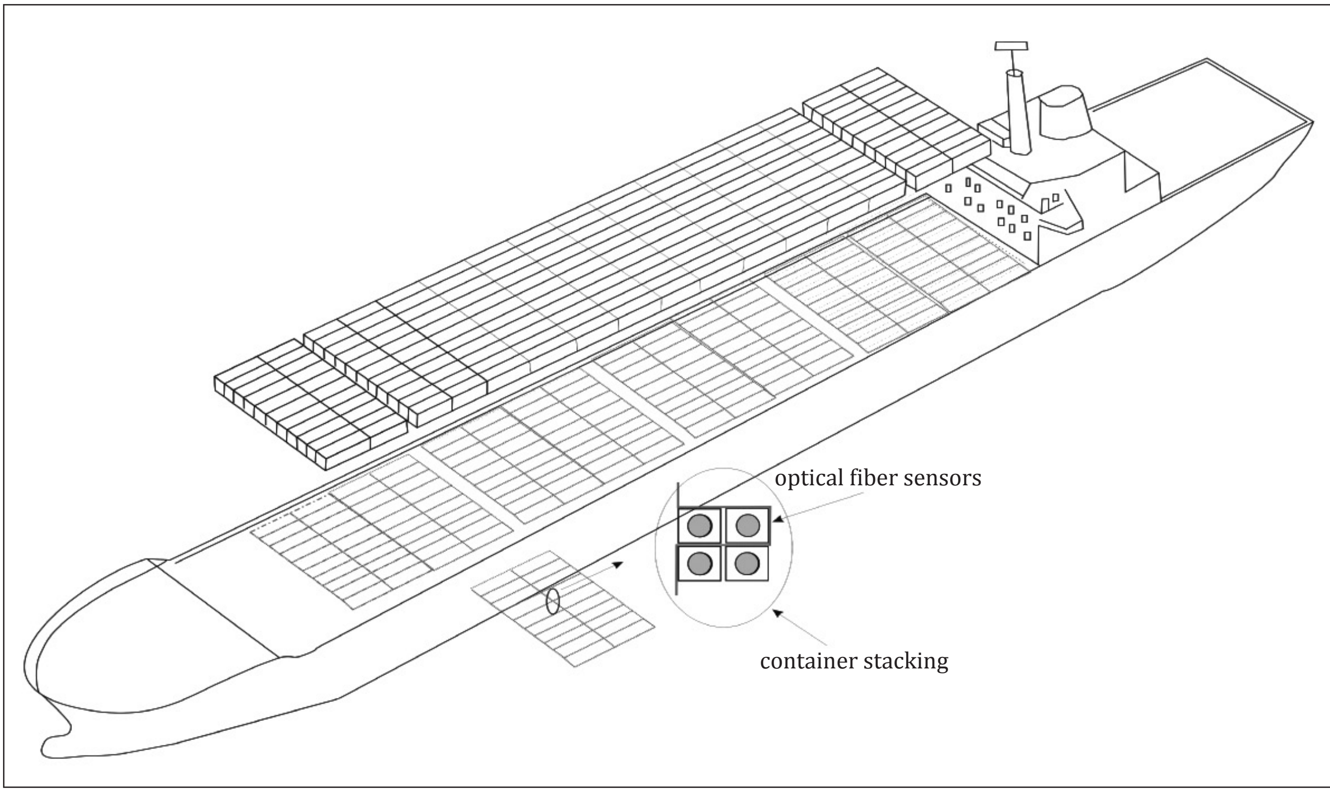

Figure 8 Load forces and strain effects monitoring system on board container ship stacking

Source: Figure 8 was created by the authors

the predictions of sea conditions obtained by the ship's traditional electronic equipment and by the knowledge of responsible ship's officers may not be sufficiently accurate to asses the real and correct condition in which the ship's cargo is [6]. The conditions of the sea are ordinary taken visually by the duty officer on watch at the navigating bridge. Modern operational requirements for ultra large container ships demand an automatic monitoring of the moment sea conditions by the use of wave radars which have become a support device for the bridge watch. Wave radars provide bridge team management in the navigation process with the following important information: wave direction, maximum wave height, wave period, significant wave height [2].

Securing containers on board modern container ship is defined by high lashing standards. Those lashing standards, complying with the container securing manual which is obligatory for each container ship and properly maintained lashing equipment are fundamental measures which every container ship should have met in order to ensure safe voyage and avoid heavy container damages. The container securing system on board, and stack devices on container ships are affected by: load forces due to cargo weight and strain effects due to the ship's motion.

The container stack devices strength determination on board a container ship can be exposed to uncertainties on the actual distribution of the cargo weight, despite of the facts that actual weights of single containers can be kept under close control during loading/discharging cargo operations.

The proposed fiber optic technology provides a possibility to real time monitoring load forces, deformations and strain effects on stack devices, as a relevant part of the determined ship's lashing system for a momentary loading condition and ship's motion.

The real time monitoring stack strength system with optical fiber sensors provides an accurate real-time data about the container lashing integrity. The optical fiber sensor monitoring system is relevant especially in the case of:

– verification of the stack devices strength,
– prediction of a structural damage,
– appropriate navigational-decisions in the case of inadequate ship's motion caused by rough sea conditions.

Real time monitoring stack strength system integrated with appropriate wave radar and loadmaster in he ship's surveillance motion system can be a relevant support tool for the officer on watch (OOW), enabling safe navigational operation with the vessel within safe limits at optimal speed and course in the present sea conditions. The surveillance motion system should have to be equipped with predefined limits data, and should have a trial motion possibility. The required information related to the ship's motion (affected on the stacking devices strength) inside the acceptable limits could be obtained by the change of the

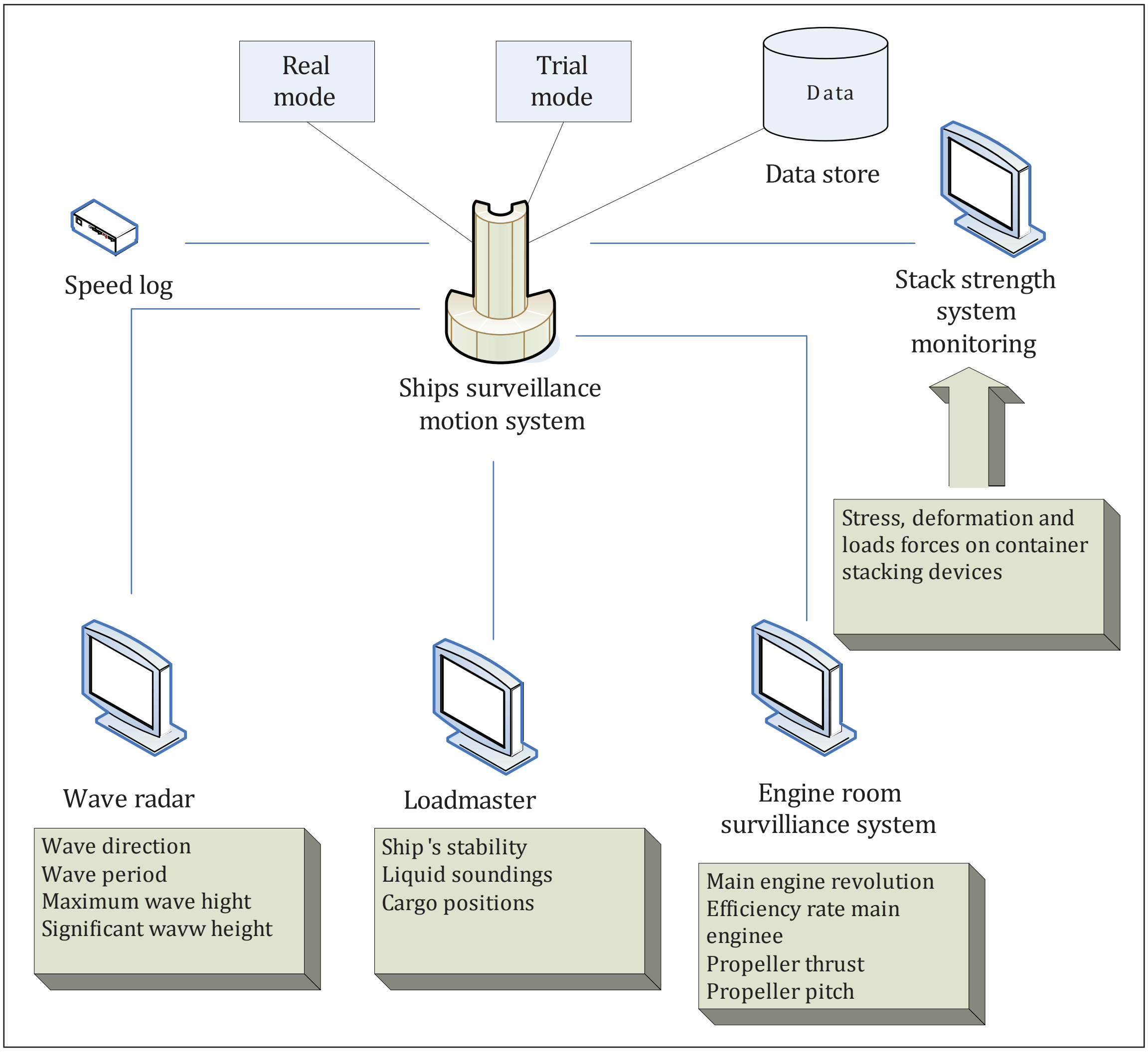

Figure 9 Integrated ship's surveillance motion system

Source: Figure 9 was created by the authors

present course/speed, by the reduction of speed, or by the change of stability parameters predefined on the system Trial motion.

7. Conclusion

The paper deals with the application of fiber optic technology on board different types of ships. Based on a theoretical analysis of the fiber optic technology, a new practical access has been expressed through the proposed application of fiber optic technology on some relevant elements in the cargo handling system. Fiber optic technology provides the possibility of a continuous monitoring of structural load forces, vibrations, liquid level readings, temperature/humidity readings and continuous supervision of relevant ship's structures and equipment. Owing to the possibility of fiber optic technology, its application on the cargo handling system elements and the belonging equipment (monitoring longitudinal/transversal strength of he ship's hull, temperature/humidity readings at cargo space and in refrigerated containers, draught readings, liquid level on tanks sounding pipes) have been proposed by the authors. Real time monitoring of relevant cargo handling elements and cargoes carried on board, by the use of optical fiber sensors enable significant information about the sea worthiness and cargo worthiness of the considered ship. The monitoring process by the use of fiber optical system on board ships permits a more effective and accurate maintenance to the responsible officer, and enables him to know that the considered element of cargo handling system has either a sustained appreciable damage or has to be excessively loaded.

The collection of relevant real-time data under adverse sea conditions and commercial ship's operations enables the ship's master/officer on watch and other interested users (ship's owner, classification societies, ship's insurance) to make correct conclusions about the ship's hull condition, cargo handling equipment and to take necessary actions. Data collected by the use of optical fiber sensors can be kept as history track on appropriate devices and/or stored on a personal computer.

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